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CAMBRIDGE RESEARCH LAB OF ELECTRON. J MELNGAILIS  
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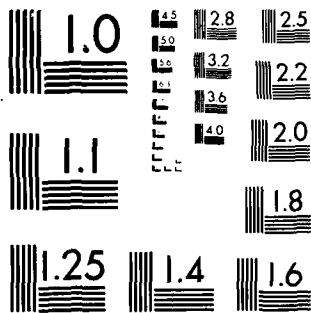
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Focused Ion Beam Fabrication  
of Graded Channel FET's  
in GaAs and Si

Semiannual Technical Report  
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by John Melngailis  
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**"Focused Ion Beam Fabrication of Graded Channel  
Field Effect Transistors in GaAs and Si"**

**Background:**

The main goals of this research program are to use the focused ion beam system for fabricating field effect transistors in GaAs and in Si with graded doping profiles, and to model the behavior of these novel device structures. The devices are fabricated by conventional processing steps except that the channel doping is performed with the focused ion beam. This permits the channel doping to be varied as a function of distance along the surface from source to drain. To achieve this goal, sophisticated performance is required from the focused ion beam system: the deflection has to be calibrated; alignment marks have to be located; rotation of the sample has to be corrected for; and a desired doping profile has to be implanted. The fabricated device must be tested, and models of the behavior developed.

**Personnel working on the program:**

Jarvis B. Jacobs, Grad. student, Elect. Eng. & Comp. Science  
Henri Lezec, Grad. student, Elect. Eng. & Comp. Science  
Christian Musil, Grad. student, Physics  
Len Mahoney, Lincoln Laboratory  
Dimitri A. Antoniadis, Associate Professor of E.E. & C.S., Coprincipal Investigator  
John Melngailis, Principal Research Scientist, R.L.E., Principal Investigator

**Progress during the Second Half-Year Period**

During this second half-year period of the research program our work has concentrated on achieving focused ion beam implants in GaAs and in Si, and



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on further developing the models of the devices which are being built.

1. GaAs FET's:

The focused ion beam system was calibrated and operating procedures were developed to perform the graded implants at the desired locations. The system has a precision x-y stage whose position is monitored with a laser interferometer with an accuracy of  $0.01\text{ }\mu\text{m}$ . This was the "ruler" used to calibrate the electrostatic beam deflection. This calibration was done by moving the stage a precise distance and then applying beam deflection to bring a given feature back to the center of the screen. In addition, rotation was corrected, and alignment to existing features was developed. The system was operated with a Au/Si source, which emits both  $\text{Si}^+$  and  $\text{Si}^{++}$  ions. Beam profiles were measured by implanting  $\text{Si}^{++}$  ions in PMMA and varying the doses over 5 orders of magnitude.

With the operating procedure developed and properly tested implants into GaAs FET's were carried out. Both  $\text{Si}^+$  and  $\text{Si}^{++}$  ions were used at accelerating voltage near 100 kV. (The system had been tested to 150 keV.) Control structures were implanted by a conventional implanter, and then identical structures were implanted with the focused ion beam. In addition, thirty FET's were implanted with a gradient of doping from source to drain. Eight different gradients were used to give a doping profile of  $n(x) = n_0(1 + \alpha x)$  where  $n_0 = 4.6 \times 10^{12}\text{ ions/cm}^2$ ,  $x$  is the distance in  $\mu\text{m}$ , and  $\alpha$  takes on eight values from 0.05 to  $0.4\text{ }\mu\text{m}^{-1}$ . Special alignment marks were ion milled into the GaAs surface to line up the gate structures with the focused ion beam implants. To achieve all of this, the focused ion beam system

was operated for four contiguous days. Considering the complexity of the system and past difficulties, we were encouraged by this performance. The standard fabrication steps are being carried out to complete the device fabrication and to test the devices.

## 2. Implantation into Si:

A set of test wafers including both n type and p type has been fabricated, which has structures for measuring both implant profiles as a function of depth and Hall coefficients. The purpose of these structures is to verify focused ion beam self annealing results reported by researchers at Hitachi, to measure the depth profile of focused ion beam implants compared to conventional implants, and to exercise the system. The conventional, control implants have been carried out, and one wafer has been focused-ion-beam implanted with  $\text{As}^+$  at 80 kV with a Pd/B/As source.

A mask set with 4 groups of 22 transistors each has been designed. Fabrications issues, such as alignment marks from level to level and alignment marks for focused ion beam implants, have had to be resolved. The mask set is now ready to be fabricated. The channel doping step of these transistors will be carried out by the focused ion beam while the other steps will be fabricated conventionally.

## 3. Modelling:

A computer simulation of the graded channel GaAs-FET's has been carried out. An existing simulation program, PISCES, has been adapted for use in GaAs. A finite element analysis predicts that with a 15% increase in doping from source to drain, a 45% increase in the

transconductance is expected while the pinchoff voltage remains constant. Calculations with a simple analytic model have also been carried out and predict improved performance as a result of grading the channel doping. In silicon the existing device models have been improved to include the effect of the dependence of mobility on depth and on the electric field generated by the gate. This is needed to correctly understand the effect of graded doping profiles on the channels of MOS devices. The functional form of the microscopic mobility model has been determined and experimentally measured mobility values have been reproduced. This model will be included in our device simulators MINIMOS and PISCES.



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